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Summary

Problem

A work capacity model has been proposed as a means of estimating both aerobic and anaerobic capacities from a series of performance measures. The relationship between power and time is modeled as a rectangular hyperbola offset by an amount reflecting a power output which theoretically can be maintained indefinitely (P_{crit}). Additionally, the amount of work that can be performed at levels above P_{crit} is fixed and referred to as the anaerobic work capacity (W_{an}). Moritani and coworkers have shown for 2 subjects that P_{crit}, but not W_{an} is decreased when the fraction of inspired O_2 (F_{IO2}) is decreased.

Objective

This study attempted to extend these findings using run time measures collected as part of a study of training at altitude.

Approach

Run times for distances of 1609, 3218, and 4,828 m were recorded at sea level (140 m) 5 days prior to (PRE) travel to 2440 m altitude, within 5 days of arrival at 2440 m (ALT), and within 5 days of return to sea level (RTN) for 19 college track athletes (13 male, 6 female). Values for critical velocity (V_{crit}) and anaerobic distance (D_{an}) were determined for each individual at each session (PRE, ALT, and RTN) as the intercept and slope, respectively, of the linear least squares regression of running velocity on the inverse of run time for the three performance runs. V_{crit} was used as an estimate of P_{crit} in the model and D_{an} as an estimate of W_{an}.

Results

There was a variation in V_{crit} with session ($p<0.001$). V_{crit} was smaller at altitude than at sea level. There was also a small but significant ($p<0.01$) increase in V_{crit} at RTN compared to PRE. V_{crit} differed between genders ($p<0.001$), but there was no gender by session interaction. D_{an} also varied with session ($p<0.001$) having decreased values at altitude relative to sea level. There were no differences in PRE and RTN values for D_{an}, no gender differences, and no gender by session interaction.

Conclusions

V_{crit} findings were in keeping with those of Moritani and coworkers, although there appears to be a difference in the magnitude of the effect of decreased oxygen tension which bears further investigation. The decrease in D_{an} is at variance with the findings of Moritani and coworkers, but may be explained in terms of the role of oxygen in lactate metabolism.

INTRODUCTION

In 1927, Hill (1927) described the relationship between human power output and time. This relationship has been modeled by Monod and Sherrer (1965), Moritani and coworkers (1981), Poole and coworkers (1988, 1996) and others as a rectangular hyperbola such as that shown in Figure 1. In this model, there is a critical power (P_{crit}), which, theoretically, can be maintained indefinitely. The total amount of work which can be carried out at rates greater than P_{crit} (the anaerobic work capacity, W_{an}) is constant. This model may be expressed in linear form, (power as a function of 1/time) as shown in Figure 2. In this form the slope and intercept represent W_{an} and P_{crit}, respectively. This model, then, offers the opportunity to investigate both endurance and anaerobic processes using a single set of two or more performance measures.

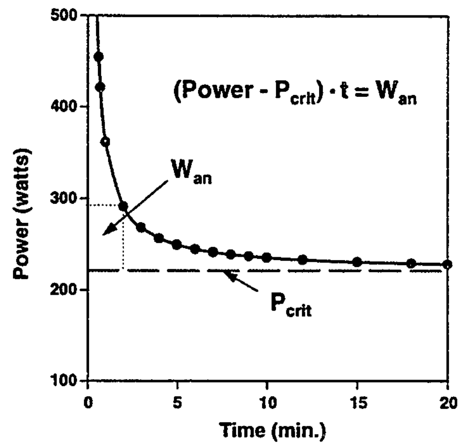

Figure 1. Work Capacity Model. (Adapted from ref. 2)

The adequacy of the work capacity model to describe the relationship between power and maximal performance has been demonstrated for cycle ergometry, running and swimming performance. When modeling running and swimming performance, the measurement of actual power output or energy expenditure rate is often difficult, and maximal velocity is substituted as an indicator of power. In such instances, the analog to P_{crit} is the critical velocity (V_{crit}). The analog to W_{an} is what might be called the "anaerobic distance" (D_{an}). (The units for the slope of a relationship between velocity (distance·time^{-1}) and time^{-1} are distance.) The validity of the constructs for this application of the work capacity model has also been demonstrated. Studies have shown P_{crit} to be strongly associated with the work rate at which blood lactate begins to accumulate. W_{an} has been associated with O_2 deficit, blood pH, and peak blood lactate values following exhaustive, short-term exercise (see Hill [1993], for review).

In their studies, Moritani and coworkers investigated the effect of decreased F_{IO2} on P_{crit} and W_{an} on two subjects performing cycle ergometry. They found decreases in F_{IO2} to associated with decreases in P_{crit} but little or no change in W_{an}. In this paper, we attempt to extend the findings of Moritani and coworkers using data from a field study which includes a natural variation in F_{IO2}.

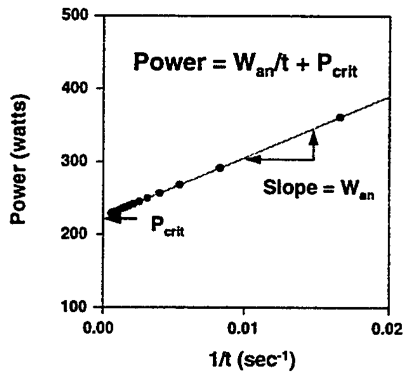

Figure 2. Linear form of the model. (Adapted from ref. 2)

MATERIALS and METHODS

Subjects in this study were 19 college track athletes, 13 male and 6 female. Physical characteristics are provided in Table 1.

Table 1. Subject Physical Characteristics*

	Males (n = 13)	Females (n = 6)
Age (yrs)	19.4 (±2.0)	18.3 (±1.2)
Height (cm)	174.0 (±4.8)	163.2 (±4.2)
Weight (kg)	60.7 (±6.5)	48.9 (±3.3)
% Fat	7.7 (±0.9)	9.6 (±3.2)
VO_{2max} (l/min)	4.0 (±0.6)	2.6 (±0.2)

*values shown are means (± std. dev.)

Run times for distances of 1609, 3218, and 4,828 m (1,2, and 3 mi., respectively) were recorded at sea level (140 m) 5 days prior to (PRE) travel to 2440 m altitude, within 5 days of arrival at 2440 m (ALT) where the subjects remained for 9 weeks of aerobic training, and within 5 days of return to sea level (RTN). The linear form of the work capacity model was applied. Running times were converted to inverse time (sec^{-1}), and running velocity was calculated from the time and distance. A least squares regression line was fitted to the 3 data points for each subject and each session (PRE, ALT, and RTN) with velocity as the dependent and $time^{-1}$ as the independent measure. The slope of the regression was used as the estimate of D_{an} and the intercept as the estimate of V_{crit} (Diem, 1962).

Altitude and gender differences among the D_{an} and V_{crit} values were assessed using a mixed design analysis of variance (ANOVA) with session (PRE, ALT, or RTN) as the within-subjects factor and gender as the between-subjects factor. Analyses were carried out using the MANOVA procedure of SPSS (1988). *Post hoc* analyses were carried out using t-tests for correlated means.

RESULTS

Mean values and standard deviations for D_{an} and V_{crit} for each testing session are provided in Table 2.

Table 2. Results*

	PRE	ALT	RTN
D_{an} (m)			
males (n=9):	276.0 (±75.0)	208.9 (±27.8)	264.9 (±45.8)
females (n=6):	240.8 (±64.3)	166.0 (±74.6)	261.3 (±51.9)
combined	261.9 (±70.7)	191.7 (±53.9)	263.5 (±46.5)
V_{crit} ($m \cdot sec^{-1}$)			
males:	4.66 (±0.38)	4.28 (±0.26)	4.79 (±0.31)
females:	3.86 (±0.26)	3.53 (±0.20)	3.96 (±0.22)
combined:	4.34 (±0.53)	3.98 (±0.44)	4.45 (±0.50)

*values shown are means (± std.dev.)

D_{an} differed significantly as a function of session ($F_{2,26} = 15.59$, $p<0.001$) with lower values at altitude than at sea level. *Post-hoc* analysis revealed no difference between the sea level D_{an} values (t_{14} PRE vs. RTN = 0.12, NS) and significant differences between altitude and each sea level value (t_{14} PRE vs. ALT = 3.90, $p<0.001$; t_{14} ALT vs. RTN = 5.44, $p<0.001$). Men and women did not differ significantly in D_{an} ($F_{1,13} = 1.2$, NS), and there was no gender by session interaction ($F_{2,26} = 0.94$, NS).

V_{crit} also differed significantly across sessions ($F_{2,26} = 88.28$, $p<0.001$), again with smaller values at altitude than at sea level (PRE vs. ALT: $t_{14} = 8.84$, p<0.001; ALT vs. RTN: $t_{14} = 14.65$, $p<0.001$). However, unlike D_{an}, there was a small, but significant increase in RTN V_{crit}, relative to PRE, following the sojourn at altitude ($t_{14} = 3.51$, $p<0.01$) suggesting a training effect. Gender differences were found for V_{crit} ($F_{1,13} = 29.71$, $p<0.001$), but there was no gender by session interaction ($F_{2,26}$ for the interaction = 0.70, NS).

DISCUSSION

The decreased V_{crit} associated with travel to altitude is consistent with the findings of Moritani and coworkers (1981). However, in this study the F_{IO2} at altitude was the equivalent of breathing 16.1% O_2 at sea level, and the average, V_{crit} decreased 8% (min. - max: 2.6% - 13.8%). This compares to decrease in P_{crit} of 20% and 36% seen by Moritani and coworkers in their two subjects when the F_{IO2} was decreased to 12% O_2, a somewhat greater change in P_{crit} per unit of F_{IO2} decrease in Moritani's subjects. This apparent difference in response may simply be the result of comparing two small samples, but it could also reflect differences in performance task time (the cycle tests were all 4 minutes or less in the Moritani study, and on the order of 5 to 25 minutes in this study), or in the power measurement (V_{O2} for Moritani's study, running velocity in the present study). These differences warrant further exploration.

The finding of decreased D_{an} with travel to altitude is not in direct agreement with the findings of Moritani and coworkers. Although 3 subjects in this study did show a small increase in D_{an} with travel to altitude. While one may tend to think that the decrease in F_{IO2} associated with altitude sojourn as only affecting aerobic processes, it should be remembered that maximal rates of oxygen uptake exceed anaerobic threshold values for oxygen uptake. When one is performing above anaerobic threshold, a portion of the oxygen taken up is used to metabolize the lactate produced. A decrease in ambient O_2 content may decrease the maximal rate of lactate metabolism and thereby decrease the anaerobic capacity.

CONCLUSIONS

The work capacity model appears to provide a convenient and useful method of estimating changes in aerobic and anaerobic support of work with changes in altitude. Based on our findings, both aerobic and anaerobic capacities are degraded with travel to altitude.

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13. ABSTRACT *(Maximum 200 words)*

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